

Comparison of radiative energy loss models in a hot QCD medium

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Abstract

The suppression of high p_T hadron production in heavy ion collisions is thought to be due to energy loss by gluon radiation off hard partons in a QCD medium. Existing models of QCD radiative energy loss in a color-charged medium give estimates of the coupling strength of the parton to the medium which differ by a factor of 5. We will present a side-by-side comparison of two different formalisms to calculate the energy loss of light quarks and gluons: the multiple soft scattering approximation (ASW-MS) and the opacity expansion formalism (ASW-SH and WHDG-rad). A common time-temperature profile is used to characterize the medium. The results are compared to the single hadron suppression R_{AA} at RHIC energies.

In addition the influence of homogeneous and non-homogeneous distribution of scattering centers is discussed. We find that using an equivalent brick overestimates the energy loss for long parton trajectories.

Keywords: Hard Probes, radiative energy loss, jet quenching

In these proceedings we present a comparison between radiative energy loss models: the multiple soft scattering approximation ASW-MS [1], and two opacity expansion formalisms ASW-SH [1] and (D)GLV [2, 3].

1. Treatment of medium geometry

We use the medium temperature T as a common variable for the different formalisms and translate this to the input parameters needed to calculate the energy loss. The participant density which is deduced from a Glauber calculation is assumed to be proportional to T^3 . We define the path integral $J_n^0(m)$ from which we calculate the relevant parameters for the two considered types of energy loss models:

$$J_n^{(m)} = \int d\tau \tau^n T^m(\tau), \quad (1)$$

where τ is the distance (time) along the parton trajectory. The density of the medium starts expanding longitudinally with $1/\tau$ at formation time $\tau_0 = 0.6$ fm. We assume a static density profile for times prior to the formation time. We assume that the parton does not interact with the medium after the temperature is below freeze-out temperature which is set at 150 MeV. Hadronization takes place in the vacuum.

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1.0.1. Multiple soft scattering approximation

For the multiple soft scattering approximation J_0^3 and J_1^3 are used in which T^3 is replaced by the local $\hat{q}(T)$ as is also done in PQM [4]. This provides an effective length and \hat{q} :

$$L_{eff} \propto \frac{2J_1^{(3)}}{J_0^{(3)}} \quad \text{and} \quad \hat{q}_{eff} \propto \frac{J_0^{(3)} \cdot J_1^{(3)}}{2J_1^{(3)}}. \quad (2)$$

1.0.2. Opacity expansion

For the opacity expansion the input parameters to calculate the single gluon radiation spectrum $dI/d\omega$ are:

$$\bar{\omega}_c \propto T^2 L \propto J_0^{(2)}, \quad \frac{L}{\lambda} \propto T L \propto J_0^{(1)} \quad \text{and} \quad \bar{R} \propto \bar{\omega}_c^2 L \propto T^2 L^2 \propto J_0^{(2)} \frac{J_1^{(m)}}{J_0^{(m)}}. \quad (3)$$

The parton momentum distribution, calculated at leading order, is convoluted with the energy loss probability distribution and the KKP fragmentation function [5] to obtain the final charged hadron spectra. The nuclear modification factor R_{AA} is calculated for a wide range of values of \hat{q} . The best fit for each energy loss formalism is determined by minimizing the modified χ^2 [6, 7]. The estimations of initial maximal \hat{q}_0 differ by a factor of 6: $20.3^{+0.6}_{-5.1} \text{ GeV}^2/\text{fm}$ for ASW-MS, $5.7^{+0.3}_{-1.9} \text{ GeV}^2/\text{fm}$ for (D)GLV and $3.2^{+0.3}_{-0.3} \text{ GeV}^2/\text{fm}$ for ASW-SH.

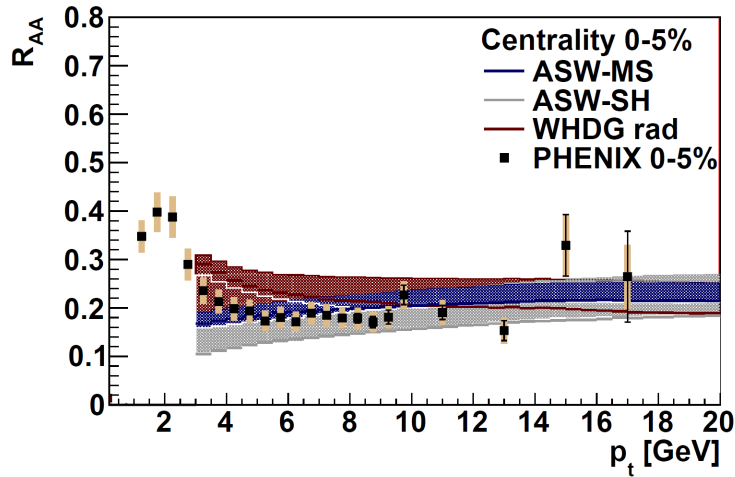


Figure 1: Best model fits for measured nuclear modification factor R_{AA} [6] for the multiple soft scattering approximation and opacity expansion formalism. Shaded areas indicate the 1σ uncertainty on the fit

2. Gluon emission at first order of opacity

The medium-induced gluon emission spectrum at first order of opacity in the GLV model [2] can be written as [8]:

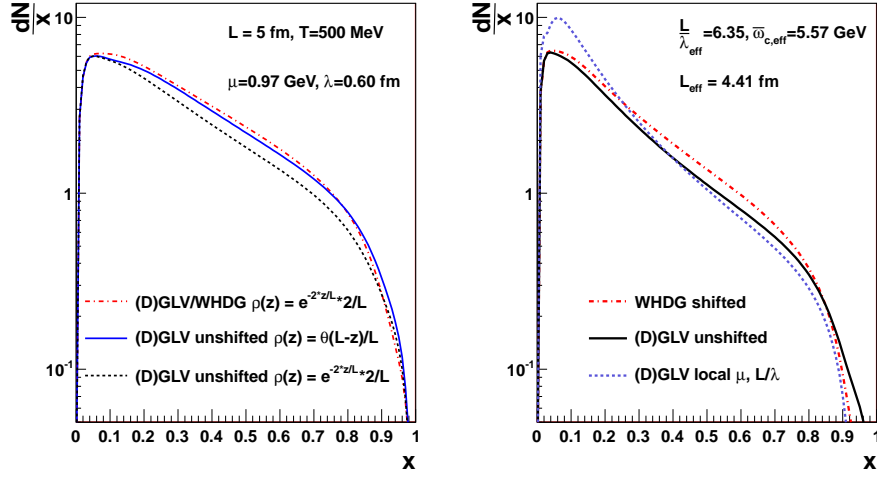
$$x \frac{dN_g}{dx} = \frac{C_R C_g g^2}{2\pi^3} \int \frac{d^2 \mathbf{q}}{(2\pi)^2} d^2 \mathbf{k} dz C(\mathbf{q}, z) \times \mathcal{K}(\mathbf{k}, \mathbf{q}, z), \quad (4)$$

in which \mathbf{k} is the transverse momentum of the emitted gluon and \mathbf{q} the transverse momentum exchanged with a scattering center in the medium,

$$C(\mathbf{q}, z) = \frac{1}{C_R} (2\pi)^2 \frac{d^2 \Gamma_{el}(\mathbf{q}, z)}{d^2 \mathbf{q}}. \quad (5)$$

and

$$\mathcal{K}(\mathbf{k}, \mathbf{q}, z) = \frac{\mathbf{k} \cdot \mathbf{q} (\mathbf{k} - \mathbf{q})^2 - \beta^2 \mathbf{q} \cdot (\mathbf{k} - \mathbf{q})}{[(\mathbf{k} - \mathbf{q})^2 + \beta^2]^2 (\mathbf{k}^2 + \beta^2)} \times \left[1 - \cos \left(\frac{(\mathbf{k} - \mathbf{q})^2 + \beta^2}{2Ex} z \right) \right]. \quad (6)$$



(a) Single gluon spectrum for GLV and WHDG implementation at same medium temperature. Normalized Yukawa potential and $\rho(z)$

(b) Comparison to single gluon spectrum with temperature profile following an expanding glauber profile.

Figure 2: Single gluon spectra

In the original GLV publications, the scattering rate $C(\mathbf{q}, z)$ is separated into three terms: the number of scattering centers L/λ , a normalised Yukawa potential and a normalised density profile $\rho(z)$.

The scattering rate per unit path length $\frac{d^2\Gamma_{el}(\mathbf{q}, z)}{d^2\mathbf{q}}$ carries all information about the density of the medium and therefore depends on the local position z of the parton in the medium.

2.1. Sensitivity to choice of density profile $\rho(z)$

In the original GLV implementation the distance of scattering centers is assumed to be an exponentially decaying distribution, $\rho(z) = \frac{2}{L}e^{-2z/L}$. Another widely used choice for the density of scattering centers is a uniform density (brick): $\rho(z) = \frac{1}{L}\theta(L-z)$ if $z \leq L$. Figure 2(a) shows the single gluon emission spectrum for these two density profiles. The curve labeled 'shifted' corresponds to the WHDG calculation [3], which uses a variable shift $\mathbf{q} \rightarrow \mathbf{q} + \mathbf{k}$ and the approximation $\mathbf{k} \gg \mathbf{q}$ for analytical convenience, for more details see [9]. In figure 2(a) we see that the three curves show a similar radiation spectrum. Within the GLV formalism the total energy loss does not strongly depend on the exact shape of $\rho(z)$.

2.2. Temperature dependence

In figure 2(b) we show an additional curve in which the scattering rate of equation 5 depends on the local temperature of the medium. We implement a Bjorken-expanding-Glauber profile and let all temperature dependent variables evolve following this profile. The parton starts in the center of the medium and moves radially outwards. The result is compared with the calculation based on an effective medium density, which is calculated using equation 3: $L/\lambda = 0.35$, $\bar{\omega}_c = 5.57$ GeV and $L = 4.41$ fm. The position dependent temperature profile enters the scattering rate via the density $N(z) = \frac{\zeta(3)}{\zeta(2)}(1 + \frac{1}{4}N_f)T^3(z)$ [10].

$$\frac{d\Gamma_{el}}{d^2q_{\perp}} \simeq \frac{C_R}{(2\pi)^2} C(\mathbf{q}, z) \simeq \frac{C_R}{(2\pi)^2} \times \frac{g^4 N(z)}{(q_{\perp}^2 + \mu^2(z))^2}, \quad (7)$$

in which C_R is the Casimir factor; $g = \sqrt{4\pi\alpha_s}$; $\mu = \sqrt{1 + \frac{1}{6}N_f} \sqrt{4\pi\alpha_s} T$, the Debye screening mass. The temperature T is the local temperature of the medium and depends on the position z of the parton in the medium. Taking into account the local temperature of the medium there is more soft gluon radiation compared to the corresponding brick.

In figure 3 we show the path length dependence of suppression factor $R_n = \int_0^1 d\epsilon (1 - \epsilon)^{n-1} P(\epsilon)$ which is an approximation for R_{AA} in a brick. The fraction of the radiated energy by multiple gluon emissions is ϵ , $P(\epsilon)$ is the energy loss probability distribution and $n = 7$ for RHIC energies. The parton is created at x_0 and travels in the positive direction on the x-axis. The suppression factor is given as function of the starting position of the parton. For short path lengths the temperature dependent description agrees with the corresponding brick. For large path lengths however the suppression of the brick is much larger than for the temperature dependent calculation.

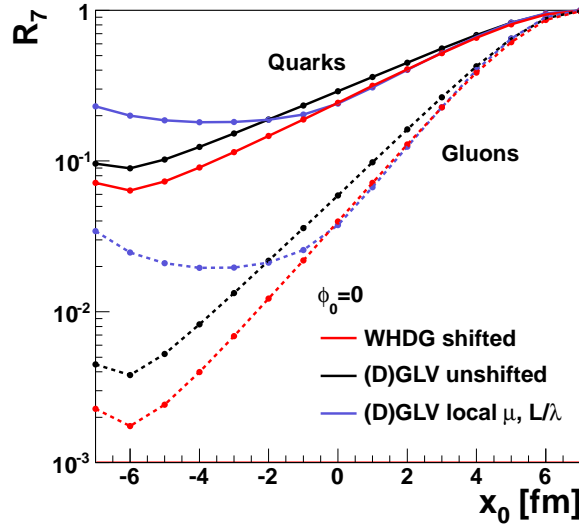


Figure 3: Suppression factor, R_7 , as function of the starting point x_0 of parton for temperature dependent distribution of scattering centers and equivalent brick

While using a common description of the density for different description of the energy loss in a hot QCD medium (ASW-MS, ASW-SH and (D)GLV) the estimated \hat{q} differs up to a factor of 5. In addition we conclude that using average medium parameters for an evolving medium overestimates the energy loss for long parton trajectories.

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